ECOLOGY

Scientists—and Climbers—Discover Cliff Ecosystems

Researchers venturing onto remote bluffs find them to be oases of diversity, but rock climbers are taking out species even as scientists discover them

They're vertical, they're made of rock, and you can't see them up close without risking your neck. So it's not surprising that few biologists have paid much attention to cliffs. But lately, some hardy researchers have dangled from ropes alongside high bluffs, and they are finding unusual and ancient communities that don't exist in the flatlands below.

These first forays have turned up surprisingly diverse communities, including rare plants and lichens, birds, and trees nearly 1000 years old. "Cliffs protect themselves very well by being so inaccessible, so they can have unusual communities even in heavily populated areas," says Jerry Freilich, former ecologist for California's Joshua Tree National Park. Joshua Tree and other parks are commissioning new studies on these hard-to-reach habitats, largely because a boom in rock climbing is putting unprecedented pressure on them, says Freilich, now science director for the Nature Conservancy of Wyoming.

Wildlife biologists have long known that raptors such as peregrine falcons and red-tailed hawks nest on cliffs, where predators can't get at their young. And a few researchers cataloged sea-cliff plants in Ireland and Britain in the 1980s. But until fairly recently, there have been no studies of cliffs as distinct ecosystems. "Look at how hostile they appear. No one really viewed them as habitat," says Richard Knight, a professor of wildlife biology at Colorado State University in Fort Collins.

Life on the edge. Ancient trees on the Niagara Escarpment are adapted to harsh cliff conditions.

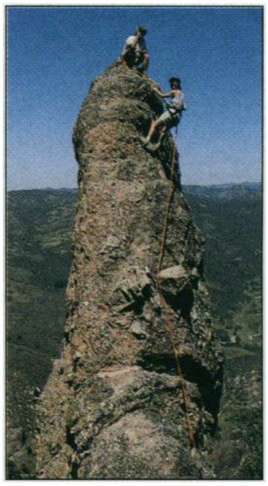
Knight and graduate student Richard Camp recently discovered that some of Joshua Tree's granite spires are actually islandlike centers of diversity. They found 60% more bird species, and three times as many plant species, on the cliffs than were on the flat, arid desert floors below. From top to bottom, the cliffs provide all sorts of niches: Rock wrens and white-throated swifts rush in and out of cracks where they nest in great chirping masses, while the prairie falcons that prey on them incubate eggs on nearby ledges. Rock faces concentrate infrequent rains, dribbling moisture down to ledges and cliff bases to supply trees and succulents such as quercus oak and staghorn cactus that won't grow elsewhere; Lazuli buntings and other Neotropical migrant birds use this vegetation for nesting and food.

Researchers are still figuring out what makes some of these rocky, windswept sites so rich. One reason is that cliffs create a classic "edge effect"—a break in the normal landscape that is often more diverse than, say, the monotonous interior of a forest. Winds that bring insects and seeds from all over may also play a role. For whatever reason, "we do know the Joshua Tree cliffs are a distinct place," says Knight.

And because cliffs are so inaccessible, organisms once widespread may end up clinging to them as sanctuaries. About 5 years ago, in a boat off the Hawaiian island of Kaui, biologists from the National Tropical Botanical Garden there spotted what they believe were the last surviving individuals of *Munroidendron racemosum*, a primitive-looking tree with long, pendulous branches. The trees were sprouting from volcanic cliff ledges that looked as if they were about to crumble into the sea. All the others of their kind, once common on the island, had been eaten by human-introduced goats that couldn't reach this one last refuge. The biologists rappelled down, rescued seeds, and have since repropagated the species, says Paul Cox, director of the botanical garden.

Cliffs in the midwestern and southern United States also are home to a host of endangered species that have either been pushed there or just prefer rocky spots. They include such plants as mud warts and water hyssops, which grow in shallow seasonal pools that form in cliff rocks in Minnesota, and lichens such as *Parmelia stictica*, which cling to vertical faces.

Lichens are often a major component of cliff ecosystems, notes biologist Michael Farris of Hamline University in St. Paul, Minnesota, but these low-profile organisms are hard to identify and poorly known. So lichen biology remains a wide-open field. Last summer, rock climber Peter Smith, then a master's student in biology at Appalachian State University in Boone, North Carolina, surveyed one small part of the walls of nearby Linville Gorge and quickly came up with 23 genera inhabiting several distinct zones according to moisture. He also spotted one entirely new species, since named *Fuscidea pallida*. "He only did 12 transects, which makes us think there are many more undiscovered things up there," says Gary Walker, Smith's adviser.



Up, up, and away. Climbers on granite spires in Joshua Tree National Monument put cliff plants and birds at risk.

CREDITS: (LEFT TO RIGHT) P. KELLY; R. L. KNIGHT/COLORADO STATE UNIVERSITY

In addition to their diversity, parts of cliff ecosystems can be remarkably ancient. Botanist Doug Larson and dendrochronologist Peter Kelly of the University of Guelph in Ontario, Canada, have found that some of the eastern white cedars dominating the 800-kilometer-long Niagara Escarpment of the Great Lakes region are up to 800 years old; well-preserved dead trees are more than twice that age.

Many of the cedars have multiple root systems attached directly to soil-less solution hollows and cracks in bare rock. Larson and his colleagues have found dense colonies of algae, bacteria, and fungi penetrating 1 to 3 millimeters into these apparently solid rocks. Larson hypothesizes that these so-called cryptoendoliths—previously known mainly from Antarctica—may help nourish the trees. Larson also notes that the cedars are apparently adapted to slow growth rates; in fact they are among the slowest growing plants known, adding only a couple of layers of cells each year, compared to perhaps 600 layers for their cousins on flat land. Twisted trunks may reach 3 feet in diameter, but some 200-year-old specimens are no bigger than a toilet plunger. Larson believes slow growth assures longevity and thus survival of the species. "It's an advantage—if they grew fast, gravity would drag them off before they got a chance to reproduce," he says.

Unfortunately, scientists are not the only ones discovering cliffs. Last year, 4 million people went rock climbing in the United States alone, and they left their mark on these fragile ecosystems, as Knight and Camp report in studies in the December 1998 issue of *Conservation Biology* and the April issue of the *Wildlife Society Bulletin*. Some Joshua Tree prominences are now hung with so many ropes that they look like Gulliver tied down by Lilliputians. To keep regular routes safe, climbers routinely "garden" them, pulling plants and soil out of cracks and wire-brushing lichens off protruding handholds.

Not surprisingly, Knight and Camp's studies show that climbers reduce plant cover and drive off birds. Independent botany consultant Victoria Nuzzo of Rockford, Illinois, showed that climbers reduced lichen cover and species by half and took out three-quarters of threatened cliff goldenrod plants at one site in northern Illinois's Mississippi Palisades State Park. Perhaps worst of all, climbers on the Niagara Escarpment are clearing the way by cutting down the old trees. Survivors may be used to fasten ropes, which strips their bark. Dendrochronologist Kelly has meticulously documented the damage; he dated one tree that germinated in 1215—and had its main axis sawed off in 1992.

Because the recognition of cliff life is so new, few parks have gotten around to making rules. As studies build, that may change. "I like to think that the more we learn about these places, the more we can demonstrate how special they are," says Kelly. —**KEVIN KRAJICK**

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BIOTECHNOLOGY

Engineering Metabolism For Commercial Gains

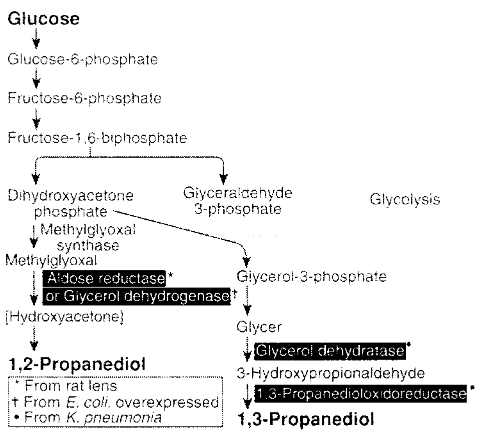
Researchers are using genetic engineering to turn bacteria into chemical reactors that perform multistep synthesis of bulk chemicals

The chemical industry is going back to the future. Until the 1930s, most bulk chemicals came from microbes, which made them by fermenting biomass such as corn and potatoes. But after learning how to "crack" petroleum into simpler hydrocarbons, chemists took over. They devised complex, multistep schemes to convert these building blocks into bulk chemicals as well as smaller scale specialty products. Now, microbes are poised to reenter the bulk chemical business.

Two decades of advances in microbial genetics and a new understanding of cells' metabolic pathways are helping researchers turn microbes into one-pot chemical reactors, able to perform multiple enzymatic steps to convert sugars and other raw materials into industrial chemicals or pharmaceuticals. By combining several chemical steps into one reaction vessel, so to speak, the strategy can save large amounts of money. As a result, the chemical industry is now getting set to reintroduce fermentation as an economical means of producing many bulk chemicals.

For example, DuPont, in Wilmington, Delaware, is planning to put a modified bacterium to work turning glucose into 1,3-propanediol, a monomer that can be linked to form a polyester called polytrimethylene terephthalate, now found in some carpeting and textiles. "We have a tremendous opportunity here to make an impact with a highly efficient and cost-effective biological process," says Richard LaDuca, the project coordinator at Genencorp International in Rochester, New York, which is working with DuPont. Two different multistep processes are now used commercially to make 1,3-propanediol.

Genencorp is also working with Eastman Chemical, of Kingsport, Tennessee, to commercialize a microbial process that transforms glucose into 2-keto-L-gulonic acid, the key intermediate in the industrial synthesis of ascorbic acid (vitamin C). The collaboration—which included several other companies and Argonne National Laboratory, in Argonne, Illinois—engineered an undisclosed bacterium to carry out the four-step metabolic pathway. According to chemical engineer Michael Cushman, Eastman's project director, this biological process is now, "without a doubt, the cheapest way to make ascorbic acid." If adopted, this one-step process would replace the current seven-step method.



Microbial industry. Equipped with genetically engineered enzymes (green), bacterial metabolism can transform glucose into propanediol.

Other chemical companies are also trying to harness microorganisms to produce bulk chemicals. But they are generally tight-lipped about their efforts, because of both the financial stakes and the strategy's history of difficulties. "Replacing chemistry with biochemistry was one of the very first things to cross people's minds when genetic engineering first came about in the early 1980s," says Douglas Cameron, recently hired away from the University of Wisconsin, Madison, by food-processing giant Cargill to build a metabolic engineering group at its Minneapolis research and development center. "But to do this on a commercial scale was a far more difficult task than anyone thought."

"Putting the new enzymes into an organism is really the easy part," adds Bernhard Palsson, professor of bioengineering at the University of California, San Diego. Indeed, it can be almost trivial, says Cameron, who is more forthcoming than many others working in industry. Developing bacteria capable of producing 1,2-propanediol—used today as a food additive, particularly for making semimoist pet food—took him and his group just a month, he notes.

They took advantage of *Escherichia coli*'s ability to convert glucose into small amounts of the compound methylglyoxal as a normal part of sugar metabolism. They knew that either of two enzymes—aldose reductase or glycerol dehydrogenase—would turn methylglyoxal into 1,2-propanediol. By consulting online databases, the group identified the appropriate genes for the enzymes and engineered them into *E. coli*. Current production of 1,2-propanediol by this engineered *E. coli* is a mere 0.2 grams per liter, "but these are our initial results and far from optimized," explains Cameron. He sees no reason to doubt that further engineering will increase production to the 100-grams-per-liter level needed to make the process commercially viable.

But coaxing a bacterium to shift much of its metabolic resources into making a particular compound is a challenge nonetheless. The production of an individual metabolite via a particular pathway is affected by the ebb and flow of dozens of other pathways in a cell's metabolism. "Eventually, you have to start looking at metabolic fluxes in the organism, in an attempt to choose pathways to get rid of or down-regulate in order to shunt more metabolic energy into the pathway you've engineered," says Palsson.

He and others, including James Bailey of